# Interference Management for D2D Communications Underlying Cellular Networks at Cell Edge

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***Abstract*—Device-to-Device (D2D) communications underlying cellular networks enhance the network capacity and spectrum efficiency, but make interference situation more complicated. In this paper, we concentrate on managing the interference between D2D communications and cellular networks at cell edge when sharing channel resources. First of all, a scheme based on interference-suppression-area (ISA), which contains downlink part and uplink part, is proposed to classify the strength of interference between D2D user equipments (UEs) and cellular user equipments (CUEs). Secondly, power control and resource allocation are processed to reduce mutual interference inside ISA. Finally, the range of ISA is discussed, which influences the system performance heavily. The simulation results show that this interference management scheme significantly improves system performance, and the optimal system performance can be obtained by adjusting the range of ISA.**

***Keywords-Device-to-Device (D2D); interference management; cellular networks***

## I. INTRODUCTION

The development of mobile communications puts forward higher requirements on transmission rate, spectrum efficiency and network capacity. While radio frequency resources are quite limited, it has become a research hotspot to find efficient ways to fully utilize the channel resources. Because of the remarkable spectrum efficiency, D2D communications are considered as a promising solution to solve these problems.

Under the control of base station (BS), D2D communications underlying cellular networks can obtain the required frequency resources and transmit power, share resources with CUEs and improve spectrum efficiency. In addition, D2D communications reduce the burden of cellular networks, increase the system throughput, reduce the power consumption of the mobile terminal and increase the bit rate, etc. [1][2].

However, resources sharing between D2D communications and cellular networks will cause additional interferences [3]. It is likely to assign orthogonal or nonorthogonal channel resources to D2D links and cellular links. Orthogonal resources are safe but wasted. Nonorthogonal resources cause interferes but improve spectrum efficiency. Due to limited frequency resources, the nonorthogonal channel resources are more practical to be considered.

In nonorthogonal resources sharing mode, BS can adopt various resource allocation strategies with different gains and complexities. Random resources allocation is a simple way and the interferences between D2D communications and cellular networks are also random. Another simple way is that BS allocates the resources used by the CUEs which are far away from the D2D pairs. This method can make the interference between D2D communications and cellular networks as small as possible.

At cell edge, the interference between BS and D2D UEs is weak, because of pathloss. Hence, there are two main interferences existing in the system. In downlink, the interference from the D2D transmitting user equipment (TUE) to the CUEs around it, and in uplink, the interference from surrounding CUEs to the D2D receiving user equipment (RUE).

Some efforts have been taken to overcome the interferences when D2D communication underlying cellular networks [4-8]. In [4], the problem of interference management for D2D communications where multiple D2D users coexist with one cellular user was discussed. To optimize the transmit power levels of D2D users to maximize the cell throughput while preserving the SINR performance for the cellular user, the authors investigated the availability of the instantaneous or average channel state information (CSI) at the base station and studied the trade-off between the signaling overhead and the overall system performance. In [5], an interference avoiding scheme for D2D communications was proposed when frequency is persistently allocated, which did not allocate subchannels that nearby cellular users currently use via overhearing signal power of uplink cellular users and calculating the interference in the frequency domain. It is noticed that some researches utilized the interference limited area to manage the interference. In [6], the mutual interferences between D2D communications and cellular networks were restricted under the constraints by adopting the interference limited area control method in downlink. Simulation results showed that the proposed scheme can significantly improve the total capacity of cellular and D2D communication, in addition to suppressing the mutual interferences. In [7], the authors

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proposed a $\delta_D$-interference limited area control scheme to manage the interference from cellular networks to D2D communication while exploiting the same uplink resources. The results indicated that the system capacity can be improved only at a small cost of cellular communication performance. In [8], D2D communication underlying a 3GPP LTE-Advanced cellular network was considered and an interference limited local area scenario was used in system simulation. The results showed that D2D communication in this scenario increased the total throughput. However, these works didn't clarify the relationship between system performance and the range of the area. Actually, the area range has a great influence on system performance.

In this paper, an interference management scheme based on ISA is proposed to manage the interference between D2D communications and cellular networks. Firstly, the whole area can be divided into two parts by interference strength. The area with strong interference in downlink and uplink is defined as ISA. Then power control and resources allocation are applied to decrease the strong interference. Furthermore, the range of ISA is discussed. It is analyzed that the optimal system performance can be obtained by adjusting the range of ISA.

The rest of the paper is organized as follow. In Section II, the D2D communications underlying cellular networks is described and the interference problem is formulated. In Section III, the interference management scheme based on ISA is discussed in details. The simulation results are presented and analyzed in Section IV. The main conclusions are drawn in Section V.

## II. SYSTEM MODEL

### A. System Model

The system model considered in this paper is a cellular network with D2D communication underlying it and sharing resources with cellular links as depicted in Fig.1. There are M CUEs uniformly distributed in the cell and one D2D pair located at the cell edge. In downlink, BS transmits signals to CUEs, and in uplink, CUEs transmit signals to BS. The TUE transmits signals to the RUE and the maximum distance between them is D.

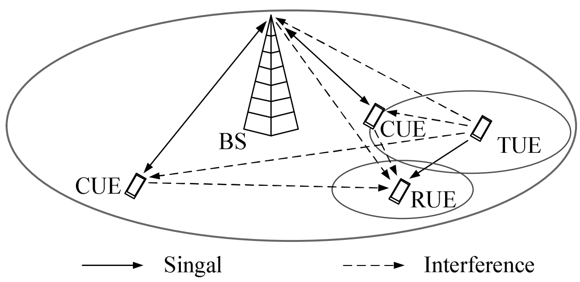


Figure 1. System model of D2D communication underlying cellular systems.

BS allocates channel resources and controls transmit power to cellular links and the D2D link. It is assumed that channels are orthogonal, and the interference only exists in intra-channel due to the channel sharing of the D2D communication and the cellular communications. Given that all channel resources, both uplink and downlink channel resources, have already equally allocated to CUEs and the number of channel resources equals the number of CUEs M, i.e., M uplink channel resources and M downlink channel resources. The D2D pair is allowed to share multiple resources, both downlink and uplink channel resources, with CUEs.

The channel considered in this paper is modeled as Rayleigh fading channel, and thus the channel response follows the independent complex Gaussian distribution. Besides, the distance-dependent path loss model is used to measure the signal power transmission loss. The channel gains contain the pathloss and the normalized small-scale fading, and we use $G_{BS,UE_k(RUE_k)}$, $G_{UE_k,BS(RUE)}$, and $G_{TUE_k,RUE(BS,UE_k)}$ to respectively represent the channel gains from BS to the k-th CUE (or the RUE) on the k-th channel resource, the channel gains from the k-th CUE to BS (or the RUE), and the channel gains from the TUE to the RUE (or BS, the k-th CUE) on the k-th channel resource.

$$\begin{aligned} G_{BS,UE_k(RUE_k)} &= PL_{BS,UE_k(RUE)} h_{BS,UE_k(RUE_k)} \\ G_{UE_k,BS(RUE)} &= PL_{UE_k,BS(RUE)} h_{UE_k,BS(RUE)} \\ G_{TUE_k,RUE(BS,UE_k)} &= PL_{TUE,RUE(BS,UE_k)} h_{TUE_k,RUE(BS,UE_k)} \end{aligned} \quad (1)$$

where $PL_{i,j}$ is the pathloss from $i$ to $j$, and $h_{i,j}$ is the corresponding small-scale fading.

### B. Problem Formulation

In downlink, BS transmits signals to CUEs and the TUE transmits signals to the RUE. Accordingly, CUEs suffer from interferences caused by the TUE and the RUE is disturbed by BS.

We denote the situation of sharing resources between the D2D pair and cellular links in downlink by array *rd(M)*, where *rd(k)* = 1 implies that the D2D pair shares the same resources with the k-th cellular link, and *rd(k)* = 0 implies that they don't share the same resource.

The SINR of the k-th CUE can be represented as:

$$SINR_{UE_k}^{DL} = \frac{P_{BS,UE_k} G_{BS,UE_k}}{rd(k) P_{TUE_k,UE_k} G_{TUE_k,UE_k} + \sigma^2}. \quad (2)$$

where $P_{BS,UE_k}$ is the transmit power of BS to the k-th CUE, and $P_{TUE_k,UE_k}$ is the transmit power of the TUE to the k-th CUE. $\sigma^2$ is the noise power.

Considering the resources allocation, the SINR of the RUE in the k-th channel resource can be represented as:

$$SINR_{RUE,k}^{DL} = rd(k) \frac{P_{TUE_k,RUE} G_{TUE_k,RUE}}{P_{BS,RUE_k} G_{BS,RUE_k} + \sigma^2}. \quad (3)$$

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where $P_{TUE,RUE_k}$ and $P_{BS,RUE_k}$ are respectively the transmit power of the TUE and BS to the RUE in the k-th channel resource.

In uplink, CUEs transmit signals to BS and the TUE still transmits signals to the RUE. Accordingly, the RUE suffers from interferences caused by CUEs and BS is disturbed by the TUE.

We denote the situation of sharing resources between the D2D pair and cellular links in uplink by array *ru(M)*, where *ru(k)* = 1 implies that the D2D pair shares the same resources with the k-th cellular link, and *ru(k)* = 0 implies that they don't share the same resource.

The SINR of BS can be represented as:

$$SINR_{BS}^{UL} = \frac{\sum_{k=1}^{M} P_{UE_k,BS} G_{UE_k,BS}}{\sum_{k=1}^{M} \left( ru(k) P_{TUE_k,BS} G_{TUE_k,BS} \right) + \sigma^2}. \quad (4)$$

where $P_{UE_k,BS}$ and $P_{TUE_k,BS}$ are respectively the transmit power of the k-th CUE and the TUE to BS in the k-th channel resource.

The SINR of the RUE in the k-th channel resource can be represented as:

$$SINR_{RUE,k}^{UL} = ru(k) \frac{P_{TUE_k,RUE} G_{TUE_k,RUE}}{P_{BS,RUE_k} G_{BS,RUE_k} + \sigma^2}. \quad (5)$$

Then the system capacity is:

$$\begin{aligned} C &= C_{DL} + C_{UL} \\ C_{DL} &= \sum_{k=1}^{M} \log_2 \left( 1 + SINR_{UE_k}^{DL} \right) + \log_2 \left( 1 + SINR_{RUE,k}^{DL} \right) \\ C_{UL} &= \log_2 \left( 1 + SINR_{BS}^{UL} \right) + \sum_{k=1}^{M} \log_2 \left( 1 + SINR_{RUE,k}^{UL} \right) \end{aligned} \quad (6)$$

where $C_{DL}$ and $C_{UL}$ are the capacity in downlink and in uplink respectively.

Thus, the optimization objective can be transformed as finding array *rd(M)* and *ru(M)* to maximize the system capacity.

## III. Interference Management Scheme

In this section, the proposed interference management scheme based on ISA is introduced in details.

### A. Power Control

In this system model, CUEs and the D2D pair coexist in the system and share whole channel resources. To guarantee the D2D communication, the transmit power of the TUE $P_{TUE}$ should be promoted as much as possible. On the other hand, large $P_{TUE}$ will cause severe interference to cellular communications which have higher priority. Hence, the $P_{TUE}$ should be controlled at a proper level.

In this scheme, we set the $P_{TUE}$ in downlink. On one hand, the interference from BS to the D2D communication in downlink can be offset effectively by power control. On the other hand, the interference from CUEs to the D2D pair in uplink is related to the distribution of CUEs, which has a great randomness and is not easy to be controlled.

To decide the $P_{TUE}$, BS sets up a SINR threshold $\eta$ and the maximum transmit power of the TUE $P_{TUEMAX}$. To ensure the quality of the D2D communication, $P_{TUE}$ should meet $\eta$ as far as possible on the premise of not exceeding $P_{TUEMAX}$.

The SINR of the RUE in the k-th channel resource should satisfy:

$$SINR_{RUE,k} \geq \eta. \quad (7)$$

Here, we define the $P_{min}$ as:

$$P_{\min} = \eta \cdot \frac{\sum_{k=1}^{M} \left( rd(k) \cdot P_{BS,RUE_k} G_{BS,RUE_k} \right) + \sigma^2}{G_{TUE_k,RUE}}. \quad (8)$$

Hence, the $P_{TUE}$ is

$$P_{TUE} = \min(P_{\min}, P_{TUEMAX}). \quad (9)$$

### B. ISA Setting

D2D communications have characteristics of short propagation distance and low transmit power. Thus the interference created by the D2D communication is quite limited. If resource scheduling was processed in the area with severe interference, which allocates the orthogonal resources to the D2D pair and the disturbed CUEs, the interference from the D2D communication to cellular networks would be reduced.

Therefore, we define an ISA for the D2D pair to indicate the area with severe interference. The CUEs and the D2D pair in same ISA will cause severe interference to each other, and require orthogonal resources.

In downlink, the receiving interference power of the k-th CUE is:

$$I_{UE_k}\left(d_{TUE,UE_k}\right) = \begin{cases} P_{TUE_k,UE_k} \cdot d_{TUE,UE_k}^{-\alpha} & d_{TUE,UE_k} > R_{DL} \\ 0 & d_{TUE,UE_k} \leq R_{DL} \end{cases}. \quad (10)$$

where $d_{TUE,UE_k}$ is the distance between the TUE and the k-th CUE, and $\alpha$ is the pothloss exponent. $R_{DL}$ is the range of the ISA in downlink ($ISA_{DL}$). Given a power threshold, indicated as $P_{DL}$, of the receiving signal from the D2D pair to CUEs. When the receiving power equals $P_{DL}$, the $R_{DL}$ can be calculated as:

$$R_{DL} = \left( \frac{P_{DL}}{P_{TUE}} \right)^{-\frac{1}{\alpha}}. \tag{11}$$

Similarly, we can obtain the range of the ISA in uplink ($ISA_{UL}$) $R_{UL}$:

$$R_{UL} = \left( \frac{P_{UL}}{P_{UE_k}} \right)^{-\frac{1}{\alpha}}. \tag{12}$$

where $P_{UL}$ is the predetermined power threshold of the receiving signal from a CUE to the RUE.

The range of ISA affects the number of channel resources can be used by the D2D communication, i.e., *rd(M)* and *ru(M)*. According to the formula (11) and formula (12), the range of $ISA_{DL}$ is related to $P_{DL}$ and $P_{TUE}$, and the range of $ISA_{UL}$ is related to $P_{UL}$ and $P_{UE_k}$. Therefore, BS can control the range of ISA by determining these parameters.

### C. Resources Allocation

When the interference between CUEs and the D2D pair is inevitable, the resources allocated to them should be orthogonal.

In this scheme, BS provides forbidden channel resources of the D2D communication in downlink, and then the TUE further determines ultimate channel resources in uplink.

In downlink, in order to minimize the interference caused by the D2D communication, the resources of the CUEs outside the $ISA_{DL}$ should be allocated to the D2D pair. For this purpose, we set up an exclusive channel D2DCH for the D2D communication to make a CUE estimate whether it is in $ISA_{DL}$ or not. In D2DCH, the TUE transmits an identifier to indicate that the D2D pair is communicating. All CUEs in community monitor this channel. When the receiving power is larger than $P_{DL}$, it indicates this CUE will be affected by the D2D communication heavily, i.e., in $ISA_{DL}$. After receiving feedback information of the CUEs in $ISA_{DL}$, BS notifies the TUE the resources allocation information of these CUEs. These resources are forbidden resources for the D2D communication.

Then, $ISA_{UL}$ is set to further determine the final used resources. The RUE monitors all channel resources. When the receiving power at certain channel resource is larger than $P_{UL}$, it indicates the CUE transmitting on this resource will affect the D2D communication seriously, i.e., in the $ISA_{UL}$. The RUE reports these resources information to the TUE. According to the feedback information from BS and the RUE, the TUE obtains information about all forbidden resources and determines the available resources. If there are no available resources, the D2D communication should wait.

By this way, BS can control the range of ISA by setting related parameters, and through resource allocation, the interference between the D2D communication and cellular networks is reduced and system performance is improved.

Moreover, it is necessary to discuss the influence on system performance caused by ISA range. With the ISA enlarges, the quantity of CUEs in ISA will increase and the cellular network performance will be improved because the interference caused by the D2D communication decreases. However, the D2D performance will decrease because the number of available resources reduces. Therefore, the system performance would not always be improved. There exist an appropriate range of ISA can make the system performance reach optimum. In this paper, we obtain the optimal ISA range by simulation.

## IV. SIMULATION RESULTS

In this section, the proposed scheme is simulated and the system performance is analyzed. The parameters are shown in Table I.

TABLE I. PARAMETERS FOR SIMULATION

| Parameter | Value |
|---|---|
| Cell Radius | 1000m |
| Distance between the TUE and the RUE | 50m |
| Number of CUEs | 30 |
| Maximum Transmit Power of BS | 46dBm |
| Maximum Transmit Power of CUEs and TUE | 23dBm |
| Noise Power | -174dBm |
| Pathloss Exponent | 4 |
| SINR Threshold of the D2D Communication $\eta$ | 10dB |

Firstly, we simulate the range of ISA with the change of corresponding power threshold. Due to the distribution of CUEs in ISA can reflect the range of ISA; we use the distribution of CUEs to illustrate the change of ISA. The D2D pair is located at the cell edge with coordinates (1000, 0). The simulation time is 200. Separately, scatter plot in Fig.2 illustrates the distribution of CUEs in the $ISA_{DL}$, Fig.3 is about the CUEs distribution in $ISA_{UL}$, and Fig.4 shows the combine situation of downlink and uplink.

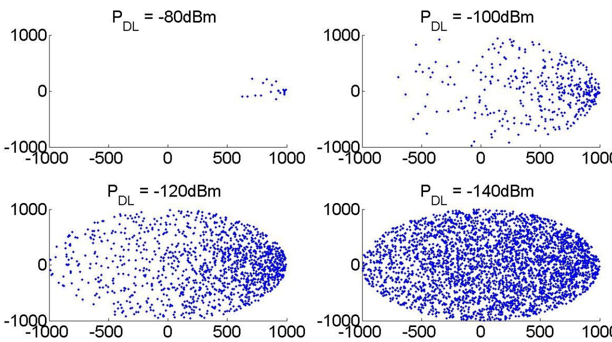


Figure 2. Distribution of CUEs in $ISA_{DL}$ with the $P_{DL}$.

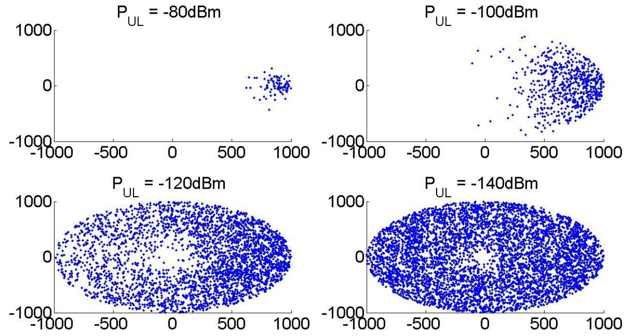


Figure 3. Distribution of CUEs in $ISA_{UL}$ with the $P_{UL}$.

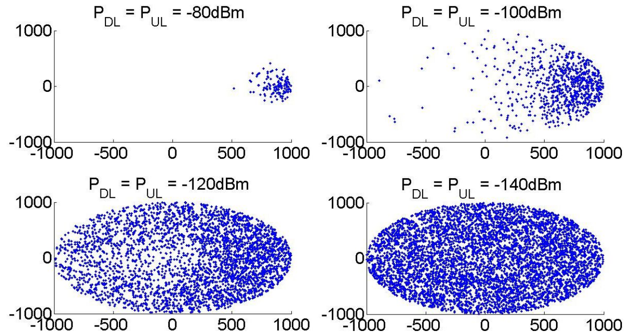


Figure 4. Distribution of CUEs in ISA with the $P_{DL}$ and $P_{UL}$.

According to the above results, with the decrease of power threshold, ISA enlarges. In uplink, due to the higher signal power, the CUEs around BS are not easily affected by the D2D communication, so when the $P_{UL}$ is small, there is a blank circle around BS in $ISA_{UL}$ as shown in Fig.3.

Fig.5 illustrates the system capacity changed with the $P_{DL}$ and $P_{UL}$.

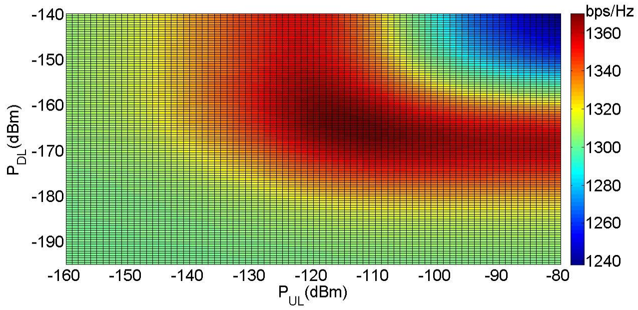


Figure 5. System capacity changed with the $P_{DL}$ and $P_{UL}$.

We can draw a few conclusions from this simulation result. First of all, as we expected, there exists an optimal value of system capacity shown as the dark red areas. The optimal value is appeared when $P_{DL}$ is around -130dBm and $P_{UL}$ is around -115dBm. Secondly, when $P_{DL}$ and $P_{UL}$ set too large, the system capacity becomes small. This is because when the power threshold is too large, fewer CUEs will enter the ISA, the interference between the D2D communication and cellular networks can't be controlled efficiently. Finally, when the $P_{DL}$ (or $P_{UL}$) is fixed, the system capacity with the increase of $P_{UL}$ (or $P_{DL}$) will first increases then decreases, there is an optimal value.

In order to assess the system performance of the proposed scheme, we compare the scheme with the random scheduling scheme which allocates the whole resources to the D2D communication as shown in Fig.6 and Fig.7. From above results, the maximum system capacity appears when $P_{DL}$ is around -130dBm and $P_{UL}$ is around -115dBm, therefore, we separately fix one of them and investigate the system capacity changed with another one.

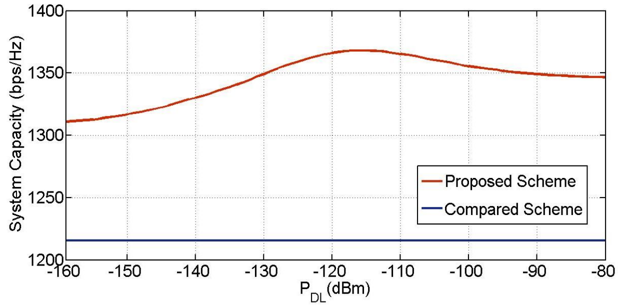


Figure 6. System capacity changed with the $P_{DL}$.

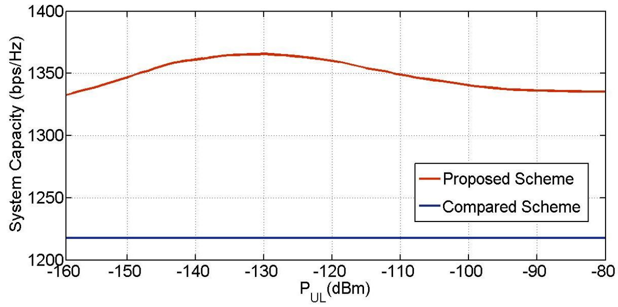


Figure 7. System capacity changed with the $P_{UL}$.

Fig.6 is the system capacity changed with $P_{DL}$ when $P_{UL}$ equals -115dBm and Fig.7 is the system capacity changed with $P_{UL}$ when $P_{DL}$ equals -130dBm. In these two graphs, the red curves represent the system capacity of the proposed scheme and the blue ones represent the system performance of the random scheduling scheme. It is obvious that the proposed scheme is superior to the compared scheme.

## V. CONCLUSION

In this paper, an interference management scheme based on ISA is proposed to manage the interference between the D2D communication at cell edge and cellular networks. BS controls the range of ISA by setting related parameters. On the premise of guaranteeing the D2D communication, BS controls the transmit power and helps determining the channel resources of the D2D communication. The simulation results show that this scheme can significantly promote the system capacity. Moreover, the range of ISA has great influence on the system performance, and the optimal system performance can be obtained by adjusting the range of ISA.

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